Emissions Modeling: **GREET** (Life Cycle Analysis) and **VISION/NEAT** (Vehicle Fleet Modeling)

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Project Overview

Timeline	Barriers
• Project start date: 10/01/2015 • Project end date: 09/30/2018 • Percent complete: 80%	• Indicators and methodology for evaluating environmental sustainability • Evaluate energy and emission benefits of vehicle/fuel systems • Overcome inconsistent data, assumptions, and guidelines
Budget	**Partners**
• Total project funding: $2.245 M (100% DOE) • Funding for FY17: $935 K • Funding for FY18: $500 K	• National labs: ORNL, NREL • Industries: OEMs and energy companies via US DRIVE • Agencies: EIA, EPA, DOT • Other org.: Jacobs, ERG

Project Overall Objectives

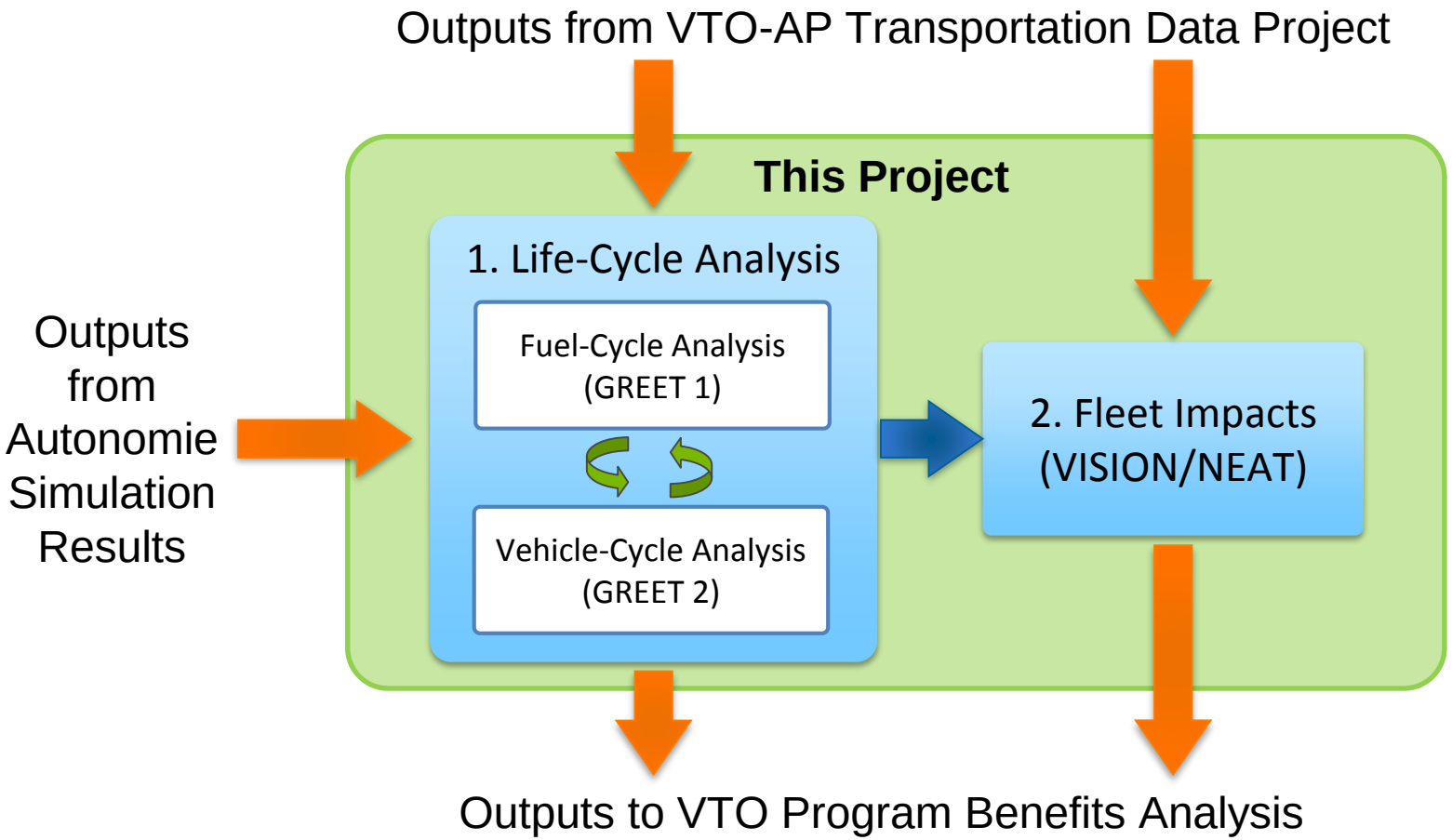
- Overcome inconsistent data, assumptions, and guidelines by developing transparent models:
  - The **GREET** life-cycle analysis (LCA) model: Holistically address energy and environmental impacts of vehicle/fuel systems with fuel cycle and vehicle cycle.
  - The **VISION/NEAT** model: Systematically assess energy and emission effects of vehicle technology deployment scenarios.

- To develop indicators and methodology for energy and environmental sustainability, and evaluate energy and emissions benefits of vehicle/fuel systems, both models include:
  - Energy use, especially related to petroleum reductions of advanced vehicle technologies and alternative transportation fuels
  - Greenhouse gas (GHG) emissions impacts of vehicle/fuel systems
  - Air pollutant emission impacts (NOx, PM10, SOx, VOC, etc.)
  - Water consumption of different transportation fuels

Task-Specific Objectives

- ***Task 1 Objective:*** LCA of vehicle/fuel systems with **GREET** covering the supply chain of a suite of fuel production pathways and vehicle manufacturing processes to generate LCA energy use, emission and water consumption results
- ***Task 2 Objective:*** Fleet-wide energy and emission assessment of advanced vehicle/fuel systems with **VISION/NEAT** by considering market potentials of vehicle technologies and fuels

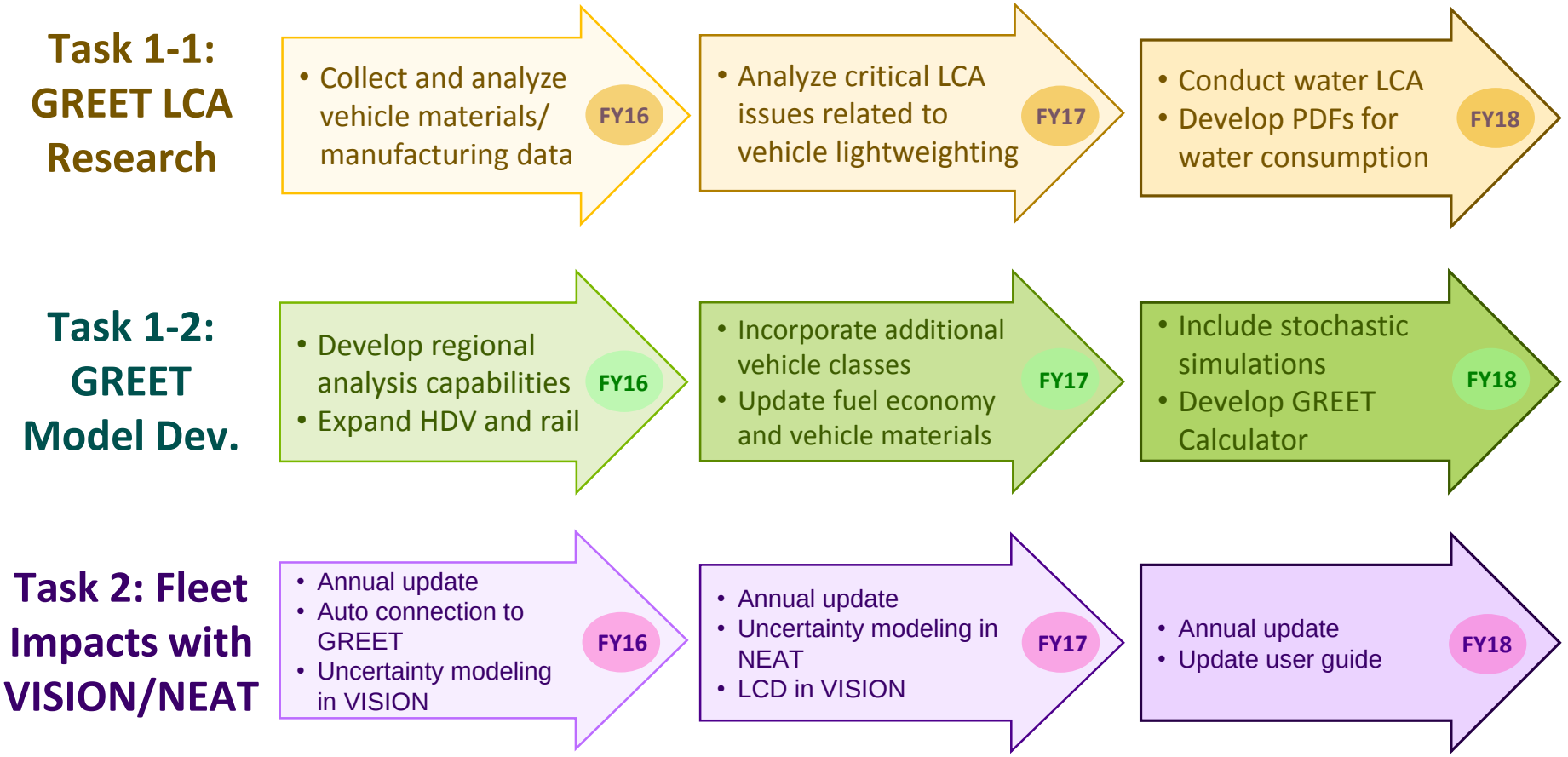
Internal Linkage among Project Tasks and External Interaction with Other VTO-AP Analysis Efforts



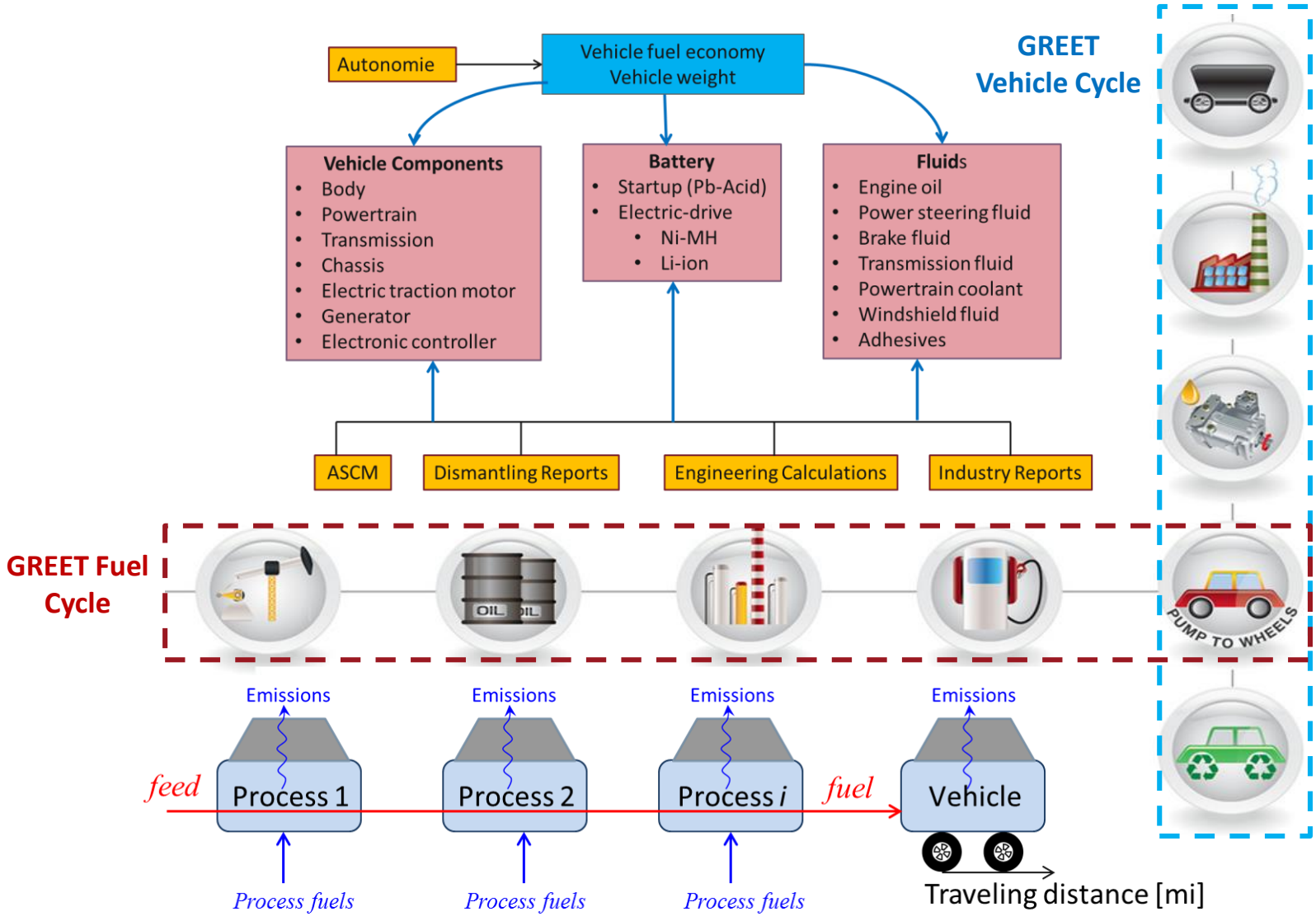
Schedule/Milestones

Schedule/milestones are determined through:

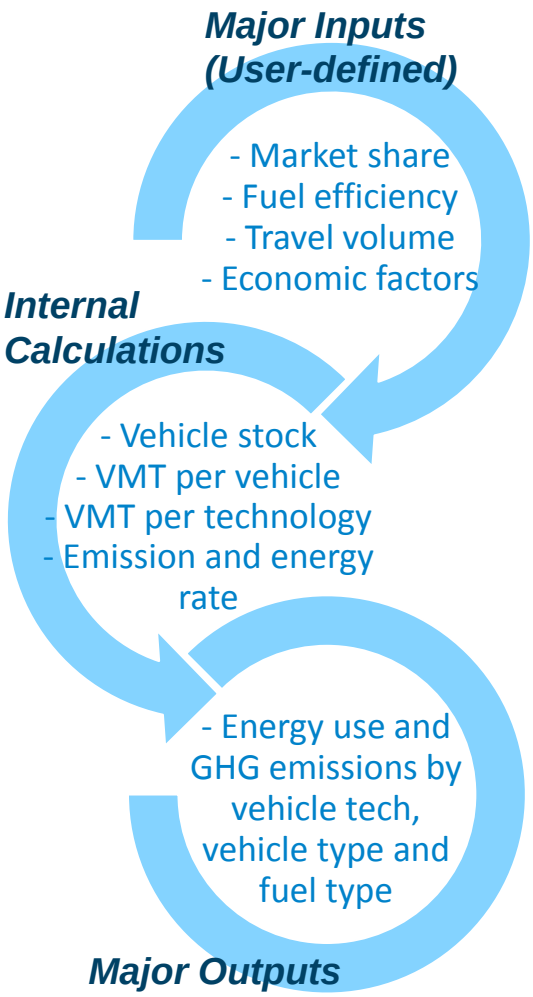
- Quarterly updates to VTO-AP sponsors
- Semi-annual ANL visits by VTO-AP sponsors
- Regular meetings with key stakeholders via USDRIVE etc.
- Reviewer inputs from VTO Annual Merit Review



GREET Life Cycle Analysis – Approach



VISION/NEAT Fleet Impact Modeling Approach



Vehicles	Technology & Fuel	Fuel Pathways
 Cars	4 ICEVs (gasoline, diesel, E85, CNG) 3 HEVs (gasoline, diesel, E85) 3 PHEVs (2 gasoline types, diesel) 2 EVs (EV100, EV200) 1 FCEV	Crude oil to gasoline and diesel Natural gas To CNG, LNG, F-T diesel Soybeans to biodiesel Corn, sugarcane, Switchgrass, etc. to ethanol Coal, nuclear, Renewables, etc. to electricity NG, coal, Biomass, etc. to H2
 Light Trucks		
 Class 3-6 Trucks	Gasoline ICEV, Diesel ICEV, CNG ICEV, Ethanol EV Diesel PHEV FCEV	
 Class 7-8 Single Unit Trucks	Gasoline ICEV, Diesel ICEV, CNG ICEV, Diesel PHEV Gasoline PHEV	
 Class 7-8 Combination Trucks	Diesel ICEV, LNG ICEV EV FCEV	

* Vehicle technologies in red were added in FY18

Approach of Regional Water Consumption Impact Analysis

GREET

Life-cycle Inventory

- Evaluate water consumption factors by region for fuel and vehicle technologies.

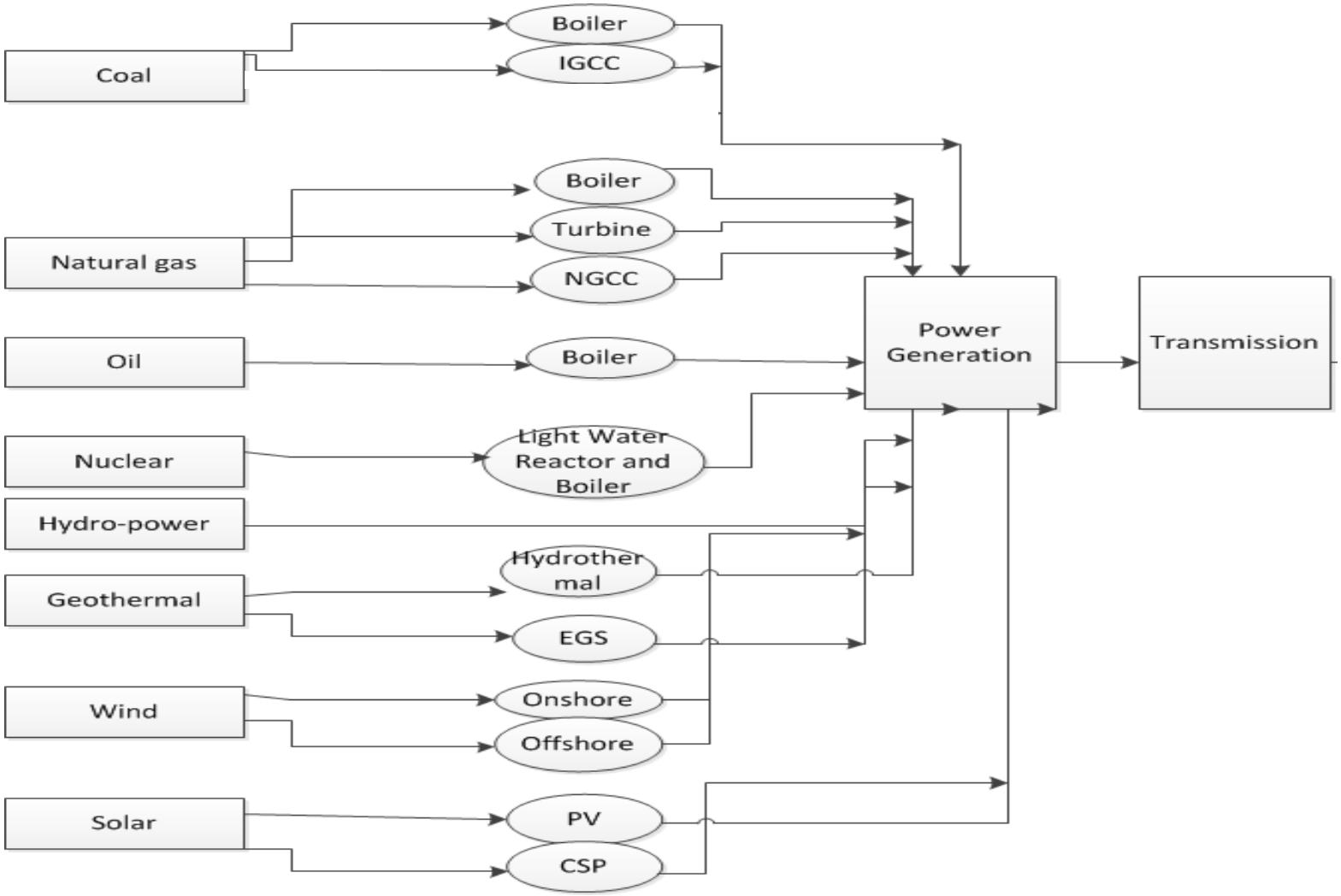
Regional Water Consumption

- Examine large scale vehicle deployment scenarios leading to additional regional water consumption

Impact Analysis

- Develop a baseline, county-level, water stress index that includes water supply and demand.
- Evaluate impact of large scale vehicle deployment on the regional water stress.

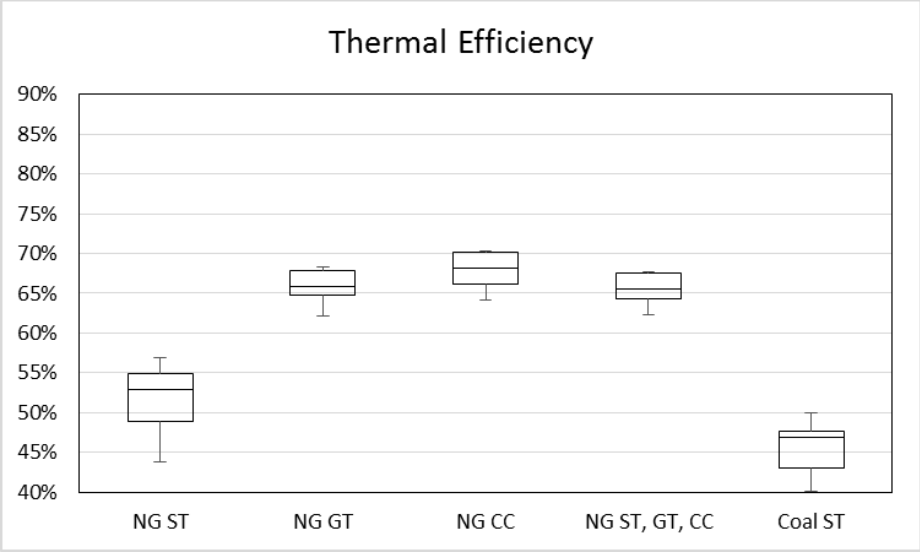
GREET Expanded to Include CHP and CCS for Coal and Natural Gas Pathways

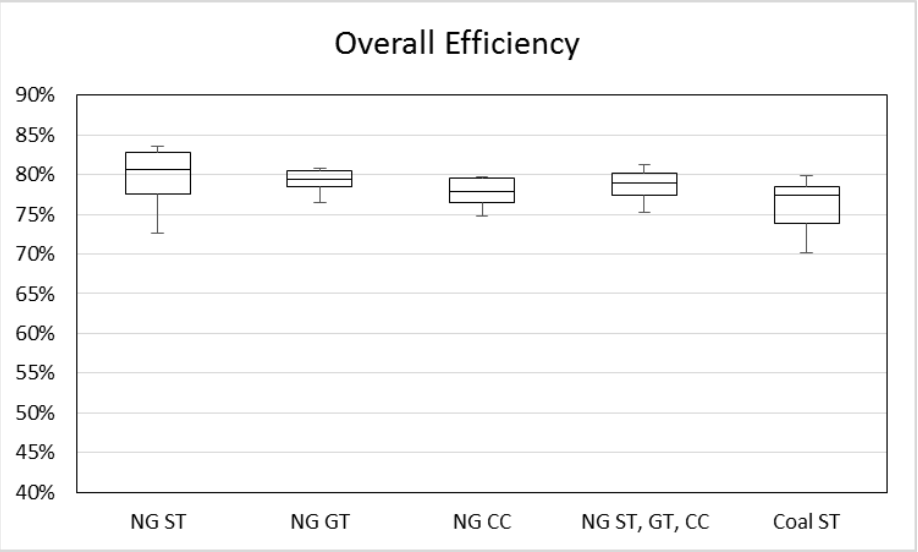


CHP = Combined Heat and Power
CCS = Carbon Capture and Storage

CHP Data In EIA Databases Were Processed and Included in GREET

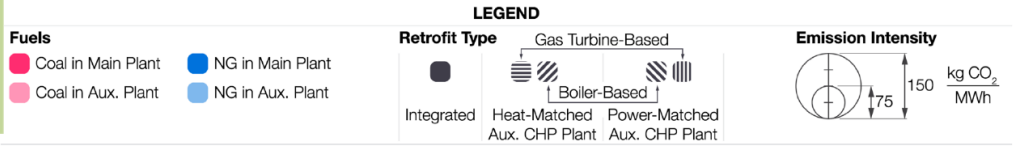
- Collected and filtered data from EIA Form 923
  - Coal: Various coal types and some extraneous categories
  - Natural gas: Several prime movers in set – consider steam turbines, gas turbines, and combined cycle plants (92% of total NG plant generation)
- Data reported on a HHV basis
  - Converted to LHV for consistency with GREET
- NAICS codes used to filter facilities by category into 7 broad groups

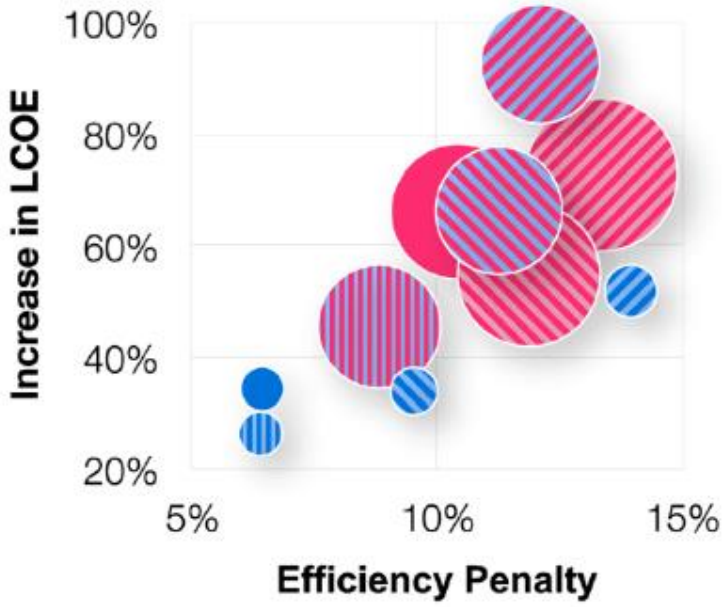




14 CCS Options Were Evaluated

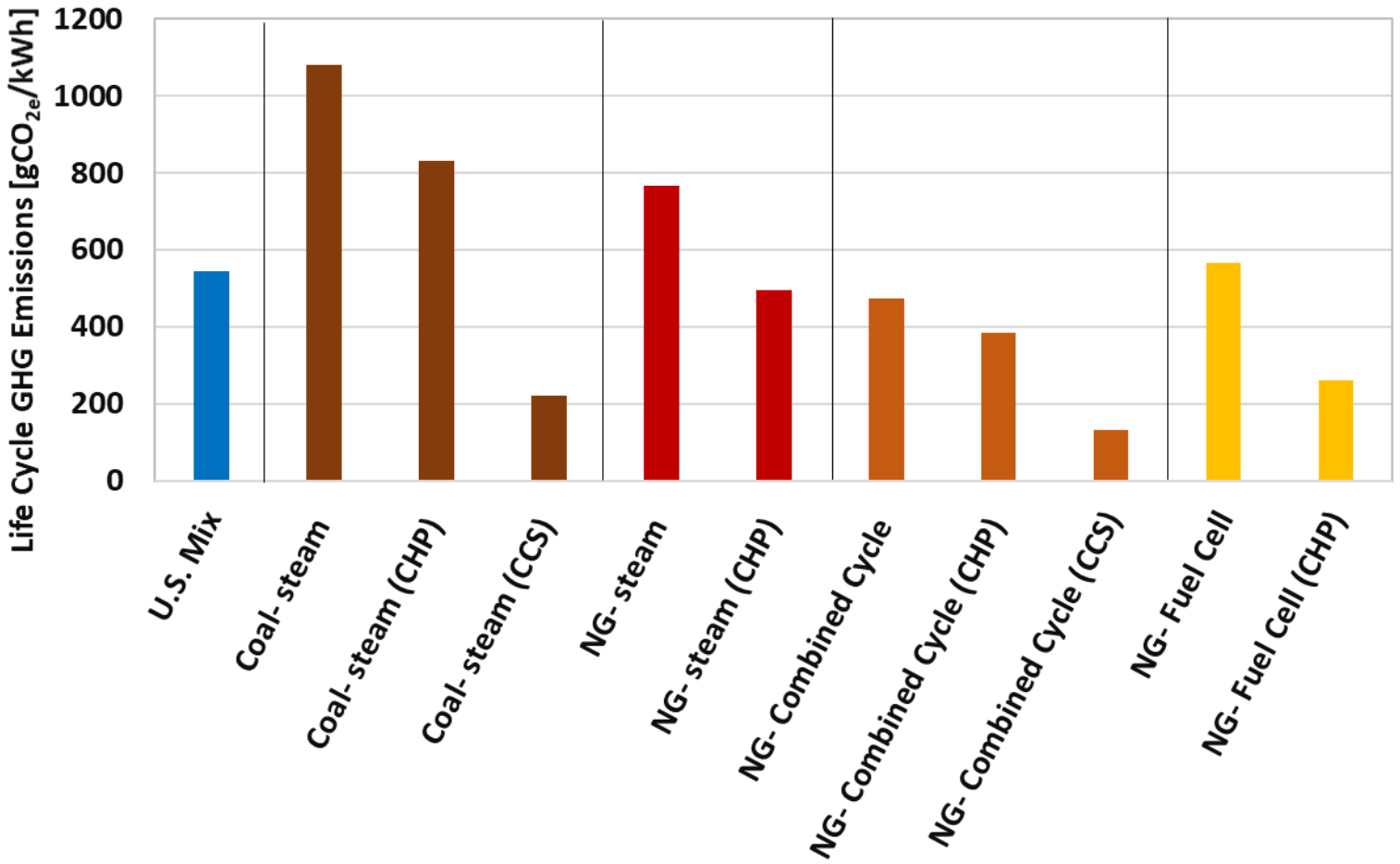
		Capture Plant Type	Aux. Plant Fuel	Aux. Plant Train	Aux. CO_2 Capture
PC-CCS	1	Integrated	X	X	X
	2	Aux. Heat-Matched	Coal	Boiler + BPT	Yes
	3	Aux. Power-Matched	Coal	Boiler + BPT	Yes
	4	Aux. Heat-Matched	Natural Gas	Boiler + BPT	Yes
	5	Aux. Power-Matched	Natural Gas	Boiler + BPT	Yes
	6	Aux. Heat-Matched	Natural Gas	GT + HRSG + BPT	Yes
	7	Aux. Power-Matched	Natural Gas	GT + HRSG + BPT	Yes
	8	Aux. Heat-Matched	Natural Gas	Boiler + BPT	No
	9	Aux. Power-Matched	Natural Gas	Boiler + BPT	No
	10	Aux. Heat-Matched	Natural Gas	GT + HRSG + BPT	No
	11	Aux. Power-Matched	Natural Gas	GT + HRSG + BPT	No
NGCC-CCS	1	Integrated	X	X	X
	2	Aux. Heat-Matched	Natural Gas	Boiler + BPT	Yes
	3	Aux. Power-Matched	Natural Gas	Boiler + BPT	Yes
	4	Aux. Heat-Matched	Natural Gas	GT + HRSG + BPT	Yes
	5	Aux. Power-Matched	Natural Gas	GT + HRSG + BPT	Yes





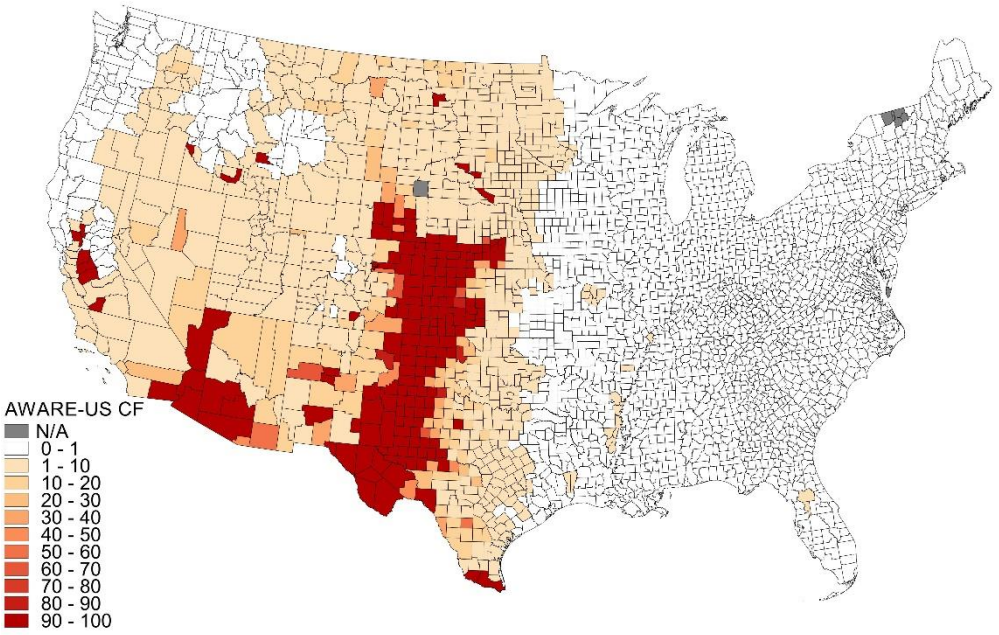
Supekar SD, Skerlos SJ.; *Environ Sci Technol*.

Life Cycle GHG Emissions of CHP and CCS

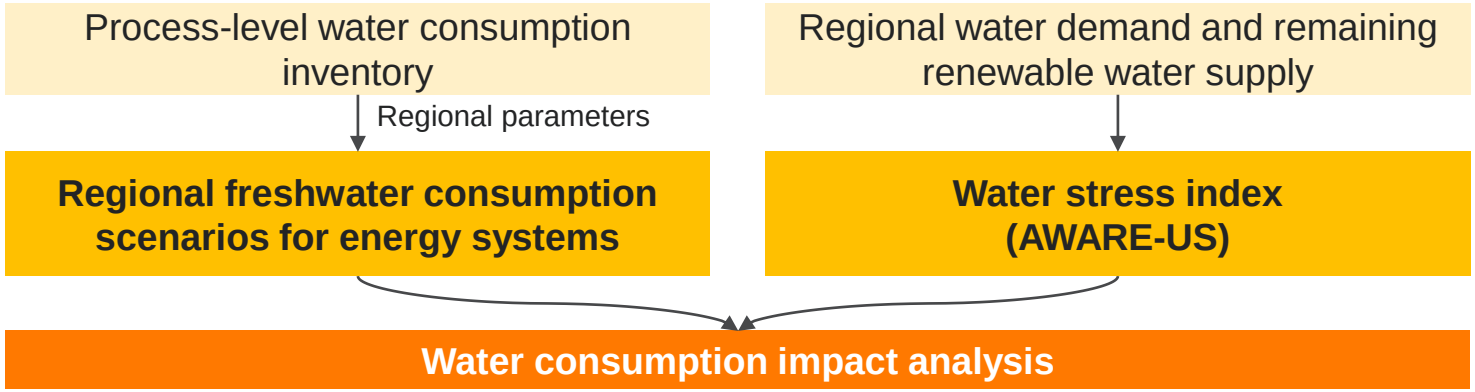


AWARE-US: County-Level Water Stress Index

- Developed a county-level baseline stress-based water index that can be applied to various fuels/vehicles enabling water consumption impact analysis



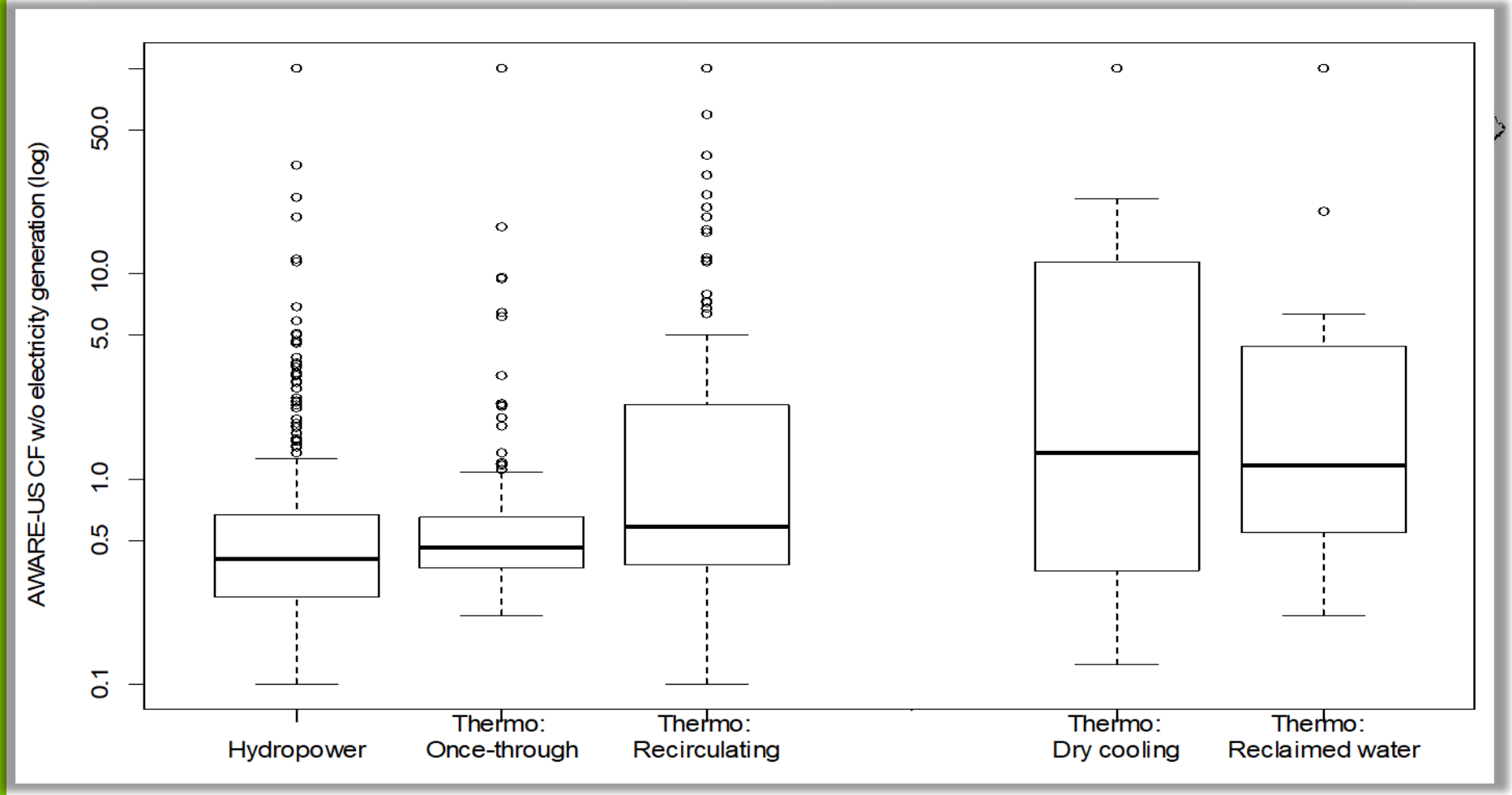
- Based on measured data
- County-level resolution
- Water consumption can be expressed in terms of “US gal equivalent” that considers water availability where it is consumed



Regional Water Consumption Distribution of Electricity Generation in the United States

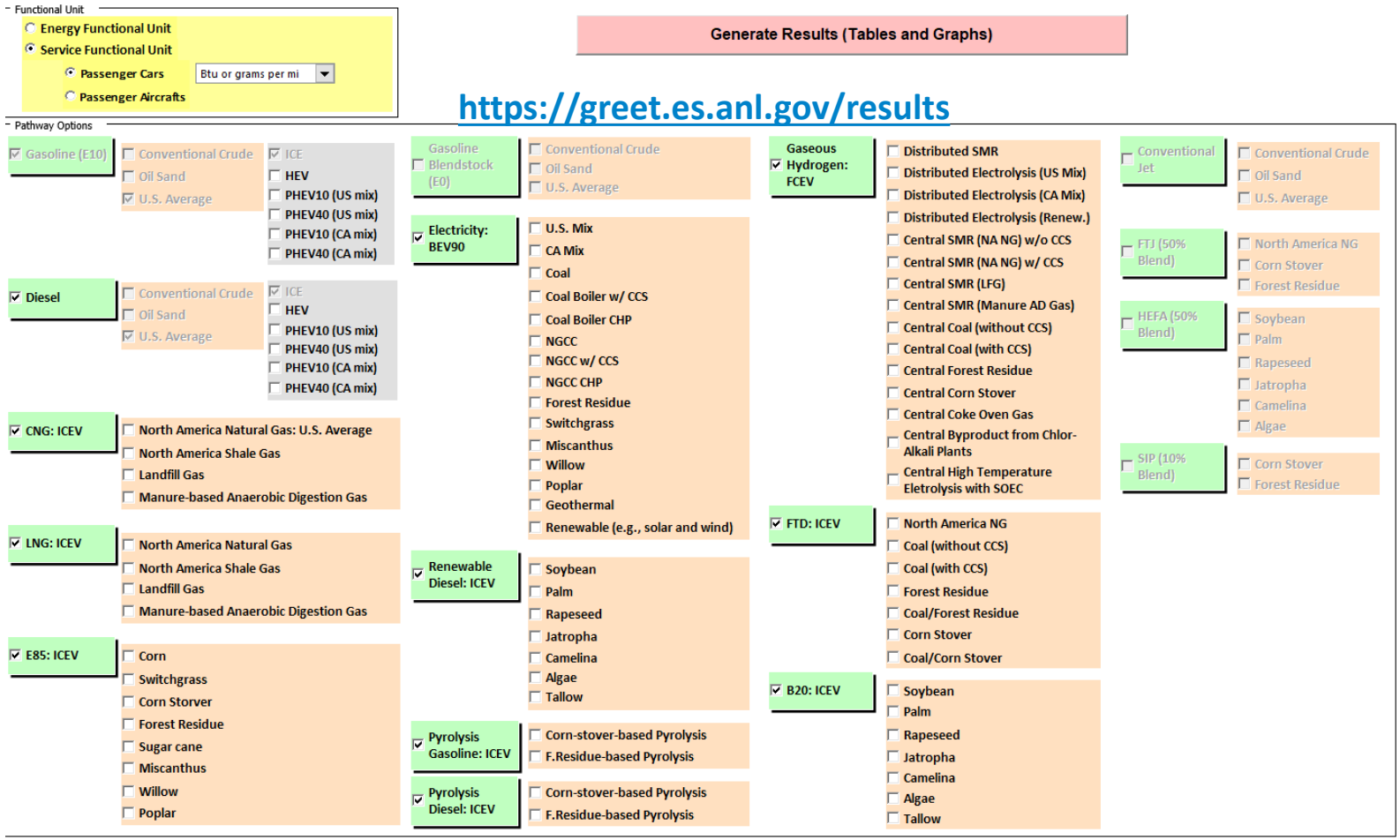
- Existing electric power generation has adapted to available water resources

Freshwater use | **No freshwater use**

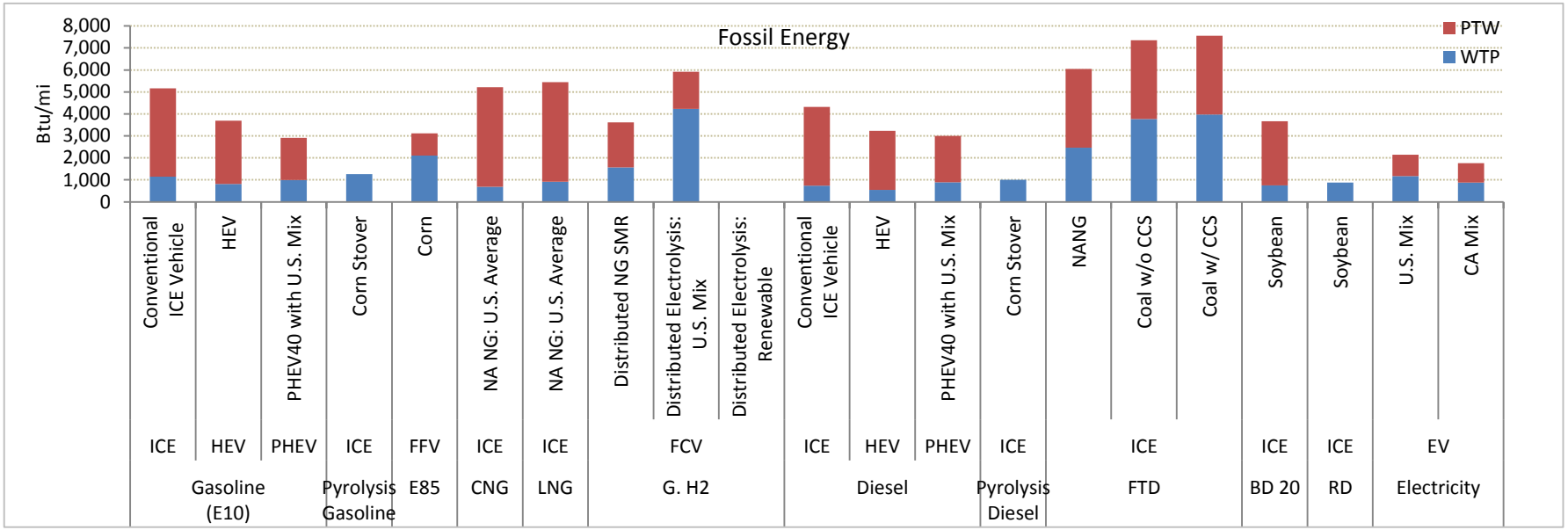


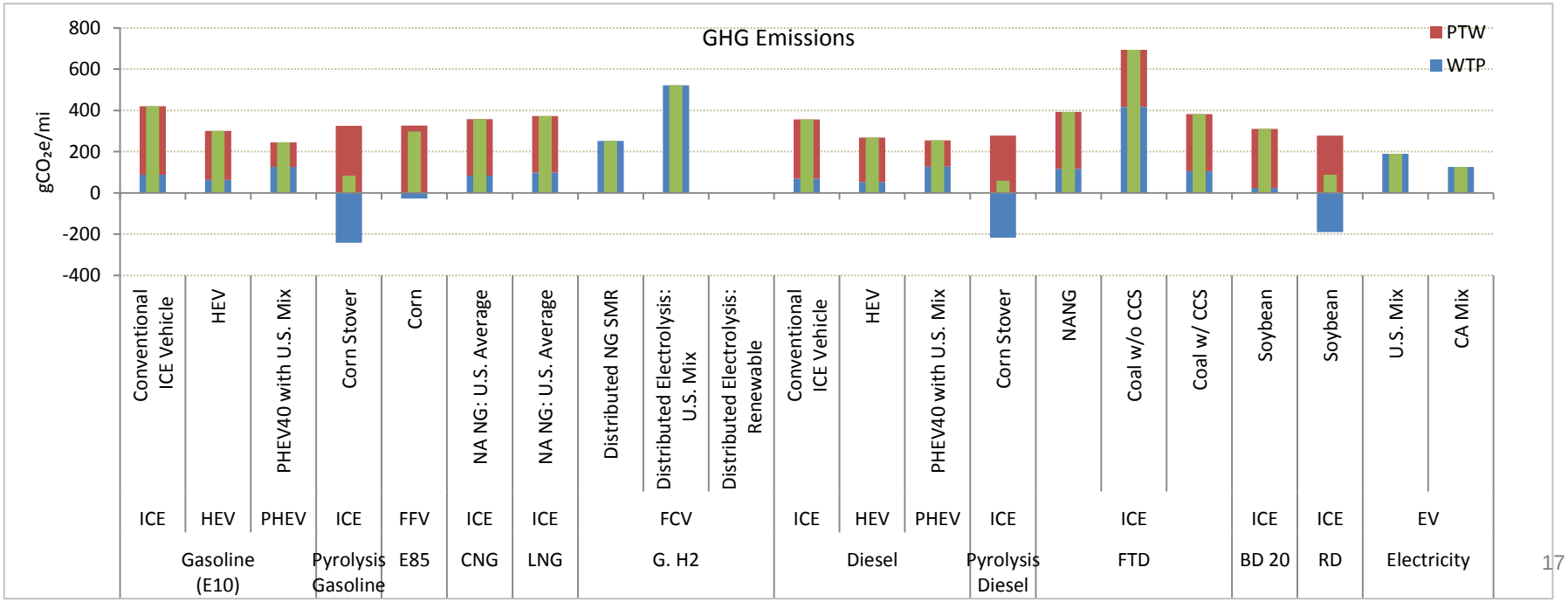
Developed GREET WTW Calculator with GREET2017 Results

- Provides readily available GREET2017 results for major fuels/vehicles
- Results: energy use, GHG emissions, and critical air pollutants
- Functional unit: per mile driven/per energy use (mmBtu, GGE, MJ)



Sample GREET WTW Calculator Results



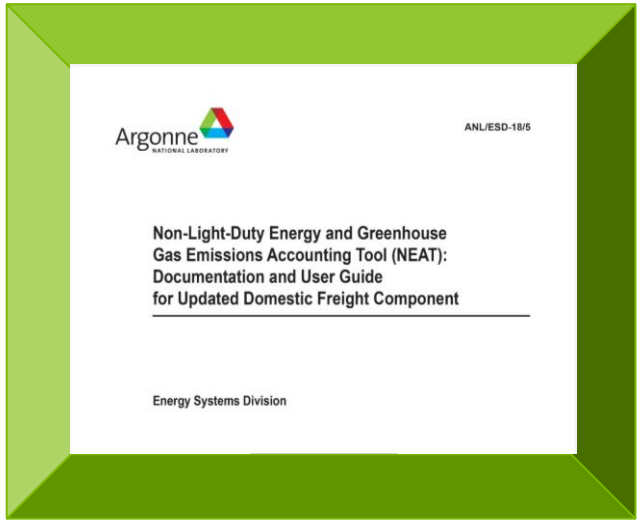


VISION/NEAT: Major Updates

VISION and NEAT were updated and calibrated to match AEO 2017 reference case

- Added alternative powertrain technologies to medium and heavy duty trucks including **plug-in gasoline electric, plug-in diesel electric, battery electric and fuel cell electric**
- Updated with energy and emission intensities from GREET1_2017
- Updated car and light duty truck survival functions due to the changes in EIA NEMS model for 2016 projections
- Updated historical Class 3-6 and Class 7&8 alternative fuel vehicle sales and stocks to match the data reported at EIA website
- Updated NEAT user guide (available online)

 Class 3-6 Trucks	Gasoline ICEV, Diesel ICEV, CNG ICEV, Ethanol EV Diesel PHEV FCEV
 Class 7-8 Single Unit Trucks	Gasoline ICEV, Diesel ICEV, CNG ICEV, Diesel PHEV Gasoline PHEV
 Class 7-8 Combination Trucks	Diesel ICEV, LNG ICEV EV FCEV

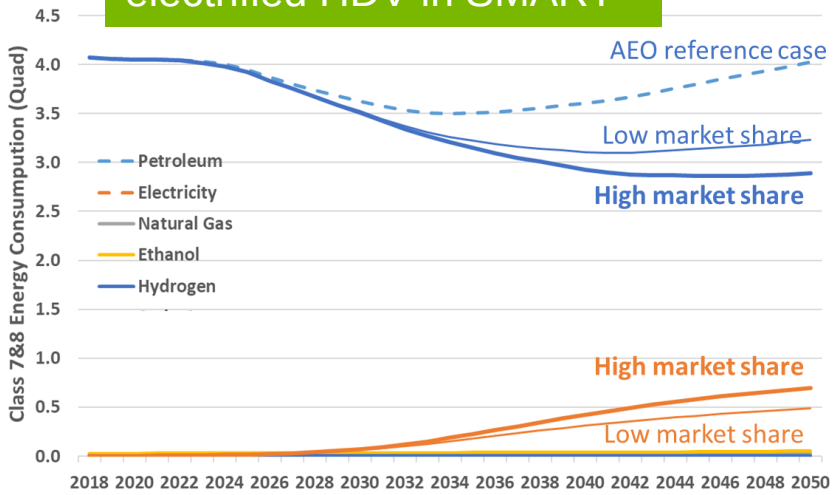


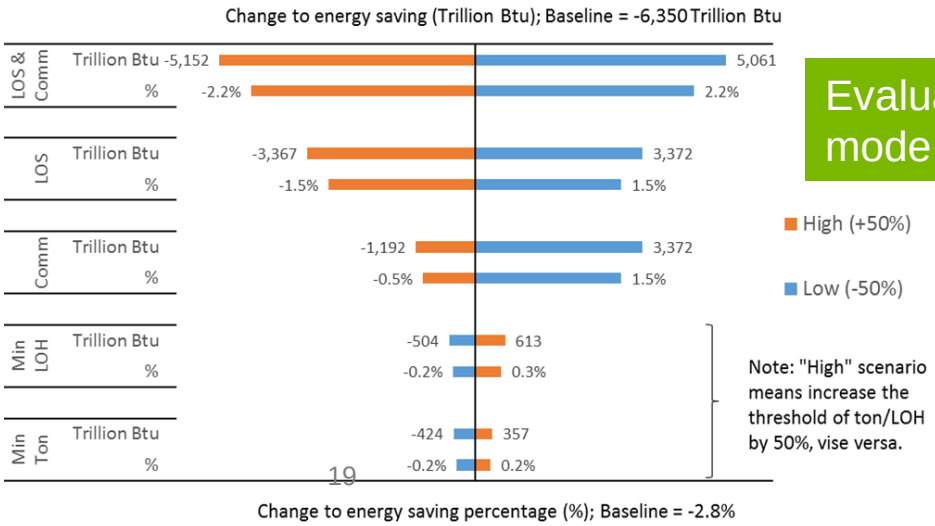
Sample VISION/NEAT Results

Results are extensively used by DOE programs and other agencies

- The models are released to public and available to download online
- Used in several DOE/EERE programs and activities such as analysis program (AP), BaSce, SMART Mobility, H2@Scale, to evaluate the impacts of advanced vehicle technologies

Evaluated platooning and electrified HDV in SMART





Evaluated freight mode shift for AP

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Responses to Reviewers' Comments on 2016 AMR Presentation

Reviewer comment	PI responses
The modeling approach is not the best choice or particularly well-suited for evaluating environmental sustainability. This, in part, derives from limitations on how the boundary and factors considered in GREET are determined. Comparing across technologies, which inherently encompass systems that have different components and input flows, is very challenging. However, GREET continues to present their results as having more usefulness and accuracy than is warranted for many of these applications, and that can be misinforming the decision-making process.	ANL constantly evaluates GREET LCA system boundary. When appropriate, ANL expands GREET system boundary to address additional issues. For example, land disturbance was including for oil sands recovery and biofuel indirect land use change has been added for biofuel LCA. On the other hand, ANL updates key data and input parameters in GREET on the annual basis to make GREET results more reliable. GREET provides consistent, transparent modeling platform for LCA of vehicle/fuel systems for comparing different systems for their sustainability merits. We believe that It has provided information to help R&D of vehicle/systems towards sustainable path. We will continue to improve it to serve this purpose to serve the over 30,000 users of GREET worldwide.
Inputs used to show results in GREET may be vetted by experts, but they are also refuted by experts. The intransigence in which the researchers have failed to consider legitimate critique and the limits it implies on how the model should and should not be used continue to linger as problems.	Data and input parameters in GREET are subject to internal and external reviews on regular basis. As stated in GREET presentation, data quality and representation are key to reliable GREET results. ANL makes GREET, its data sources and results publicly available so that critical reviews and feedbacks can be received. Whenever possible, GREET relies in primary data sources, and also support its findings through peer-reviewed publications. ANL continues to interact with researchers with critical inputs and comments to improve GREET. ANL welcomes specific comments on data limitations and modeling approaches in GREET and incorporate them as appropriate.
The approach of VISION/NEAT, and the reliance on the exogenous inputs, limits its usefulness. It is unclear if there is a mechanism to ensure that the inputs are self-consistent. As such, the model functions more as a deterministic calculator for which the output may or not be realistic or relevant for informing decision making by DOE.	We ensure that energy use by modes/subsector match historical values. All future changes are from most recent EIA AEO. VISION extends the analysis horizon by using available projections of independent variables. NEAT uses data from FAF and AEO and matches historical energy consumption. All future energy efficiency changes in NEAT are from AEO. VISION and NEAT are intended for users to evaluate energy and emission effects of vehicle scenarios relative to the base case, instead of prescribe a future and predict effects. With this scope, we believe that the models are appropriate for what they are set up to accomplish.
When evaluating fuel and vehicle emissions at a state level, electric power should reflect utility generation mix of consumption, not state production. VISION model calibration techniques should be clearly described and tested to indicate the impact calibration has on projected values.	VISION relies on GREET results of electricity emissions. GREET has the feature to develop state-specific electricity emissions based on power plant locations. To develop consumption-based electricity emissions, a valid point raised by the reviewer, requires detailed information on electricity usage patterns, power plant dispatch, and electricity transmission and trade cross state lines. These are not readily available yet for switch from production-based to consumption-based state electricity emission intensities.

External Collaboration

Collaboration/ Coordination

- USCAR via USDRIVE for GREET
  - Inputs on vehicle technology options and fuel pathway choices
  - Verification of key parameters by member companies
- National lab partners for GREET and VISION/NEAT
  - NREL: TEA outputs processed for inputs to GREET for fuel production pathways
  - ORNL: transportation energy data book provides inputs for VISION/NEAT
- Other government agencies
  - EIA: GREET and VISION/NEAT, annual updates with AEO and other publications/databases
  - EPA: Power plant emissions and renewable fuel standard pathway development
  - DOT: FAA – aviation fuels
- Research organizations
  - Jacobs Consultancy: detailed petroleum refinery LP modeling for energy, emissions and water
  - Eastern Research Group: emissions of criteria air pollutants of petroleum refineries and other major stationary sources

Remaining Challenges and Barriers

- Data availability and quality: challenges for all the models
  - Collaboration with various organizations
  - Modeling and simulations to produce required inputs
- Modeling methodologies
  - GREET: System boundary expansion and modeling of indirect effects via economics
  - VISION/NEAT: Utility factor/function for plug-in MHDVs, market uncertainty (vehicle segments/classes)
  - Water analysis: Seasonal variation in water supply and demand
- Technology/market dynamics over time
  - Need to address technology improvements and market changes as time progresses so that their effects can be reflected in GREET/VISION benefits assessment
- Metrics of modeling results
  - Energy, emissions, water, costs so far
  - Only a subset of issues for performance of technologies/systems
- Interpretation of results
  - Users sometimes have tendency to interpret results beyond modeling scope

Planned/Proposed Future Work

- GREET
  - Expand GREET to include plug-in electric medium- and heavy-duty vehicles
  - Expand GREET to include LCA of autonomous vehicles
  - Analyze critical LCA issues related to vehicle lightweighting
  - Continue development of water consumption factors for feedstocks, fuels and vehicle materials
  - Address LCA system boundary/regional issues
- VISION/NEAT
  - Annual update to match AEO reference case projections
  - Analyze utility factor/function for battery electric MHDVs,
  - Develop simplified online version for users
- Water consumption impact analysis
  - Collaborate with EPA and NETL for detailed regional water consumption impact analysis for U.S. electricity generation

Summary

- Objective of this project is to develop modeling capabilities for VTO-AP to estimate energy, environmental, and cost effects of advanced vehicle technologies and alternative fuels
- Main products of this project include a suite of widely accepted/used models (GREET, VISION/NEAT) to address key barriers in analyzing energy, environmental, costs of vehicle/fuel systems
- Model development efforts of this project are
  - Highly leveraged with ANL's efforts for other EERE programs, other VTO programs, and other VTO-AP efforts
  - Executed by ANL top-of-field experts
- Key factor for project success is the continuing interactions with DOE sponsors, other national labs, OEMs, energy companies, and universities during project